

The Warm & Hot Intergalactic Medium in Absorption with Constellation-X

Randall Smith
with help from

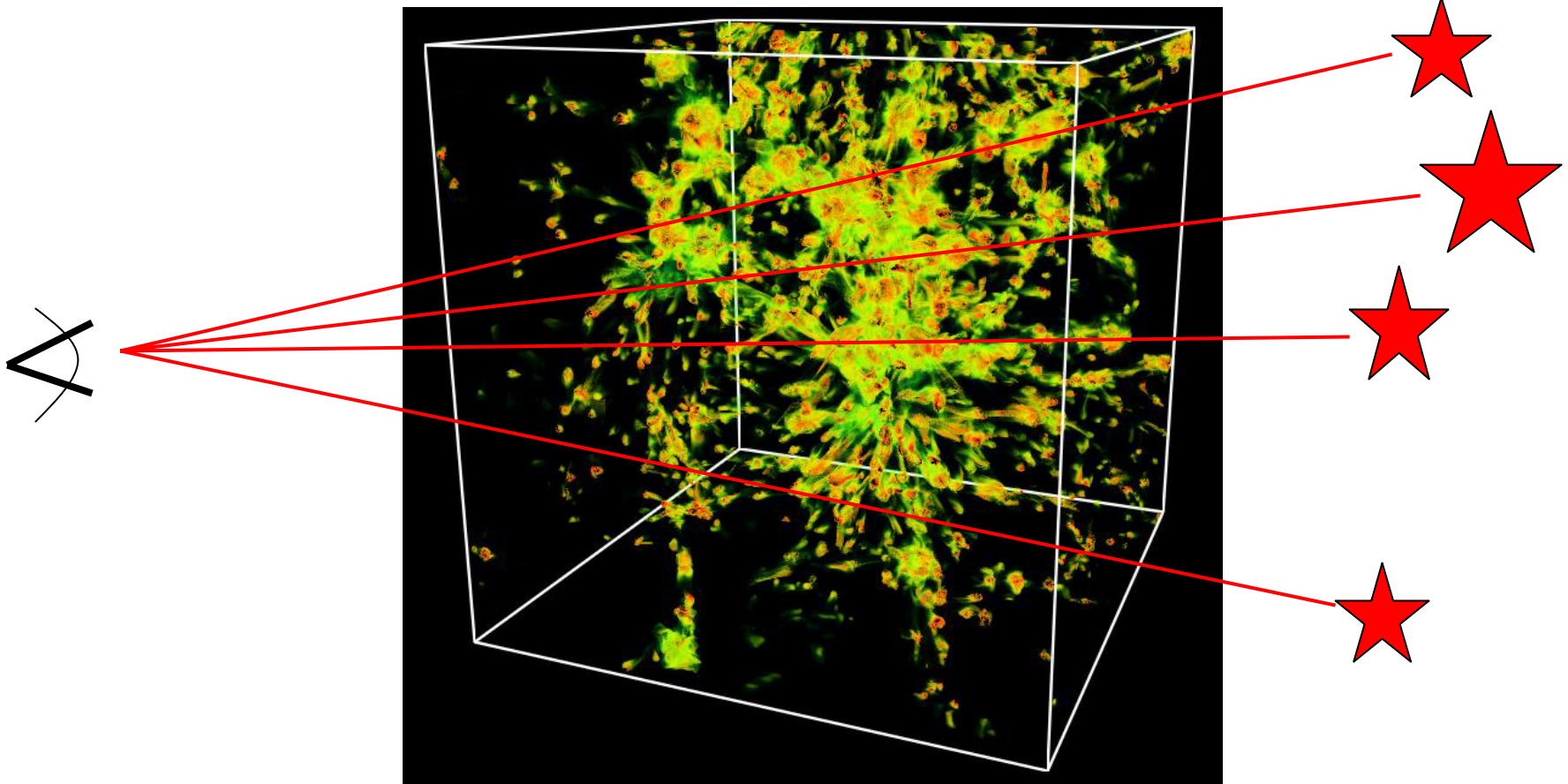
Joel Bregman, Jean Cottam, Megan Donahue
Ann Hornschemeier & Richard Mushotzky

Where is the missing $\sim 50\%$ of the 4%
of the Universe we understand?

Where is the missing $\sim 50\%$ of the 4%
of the Universe we understand?



Where is the missing ~50% of the 4% of the Universe we understand?



<http://www.astro.princeton.edu/~cen/PROJECTS/p2/p2.html>

Where is the missing $\sim 50\%$ of the 4% of the Universe we understand?

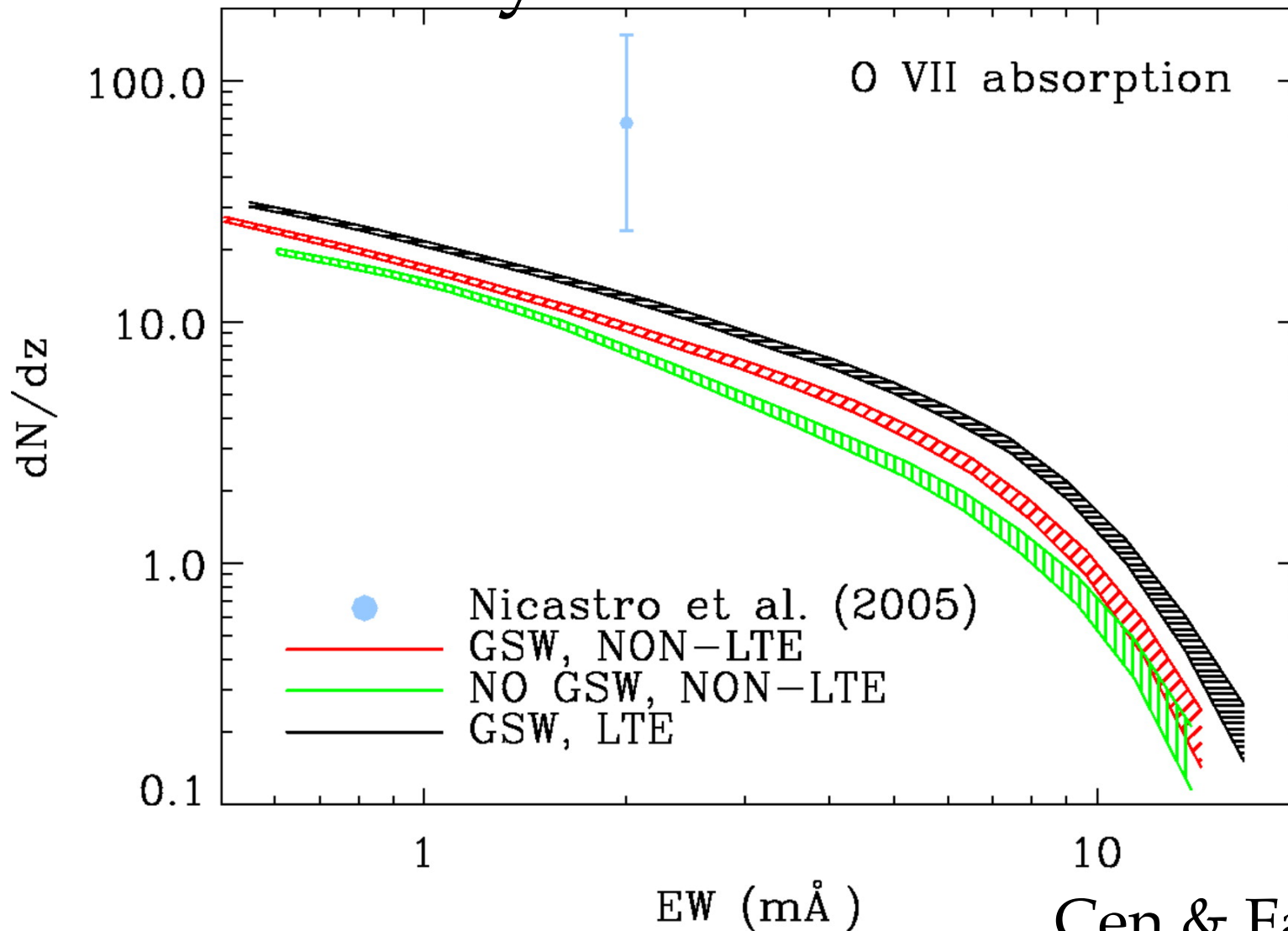
Filaments generally have $T=10^5\text{-}10^{7.5}$ K

\Rightarrow Two Methods to Search for the WHIM:

Absorption: Use background AGN to search for highly ionized O & Ne. \Leftarrow [this talk](#)

Emission: Search for diffuse O VII, O VIII usually near but outside clusters

How Many Filaments are There?

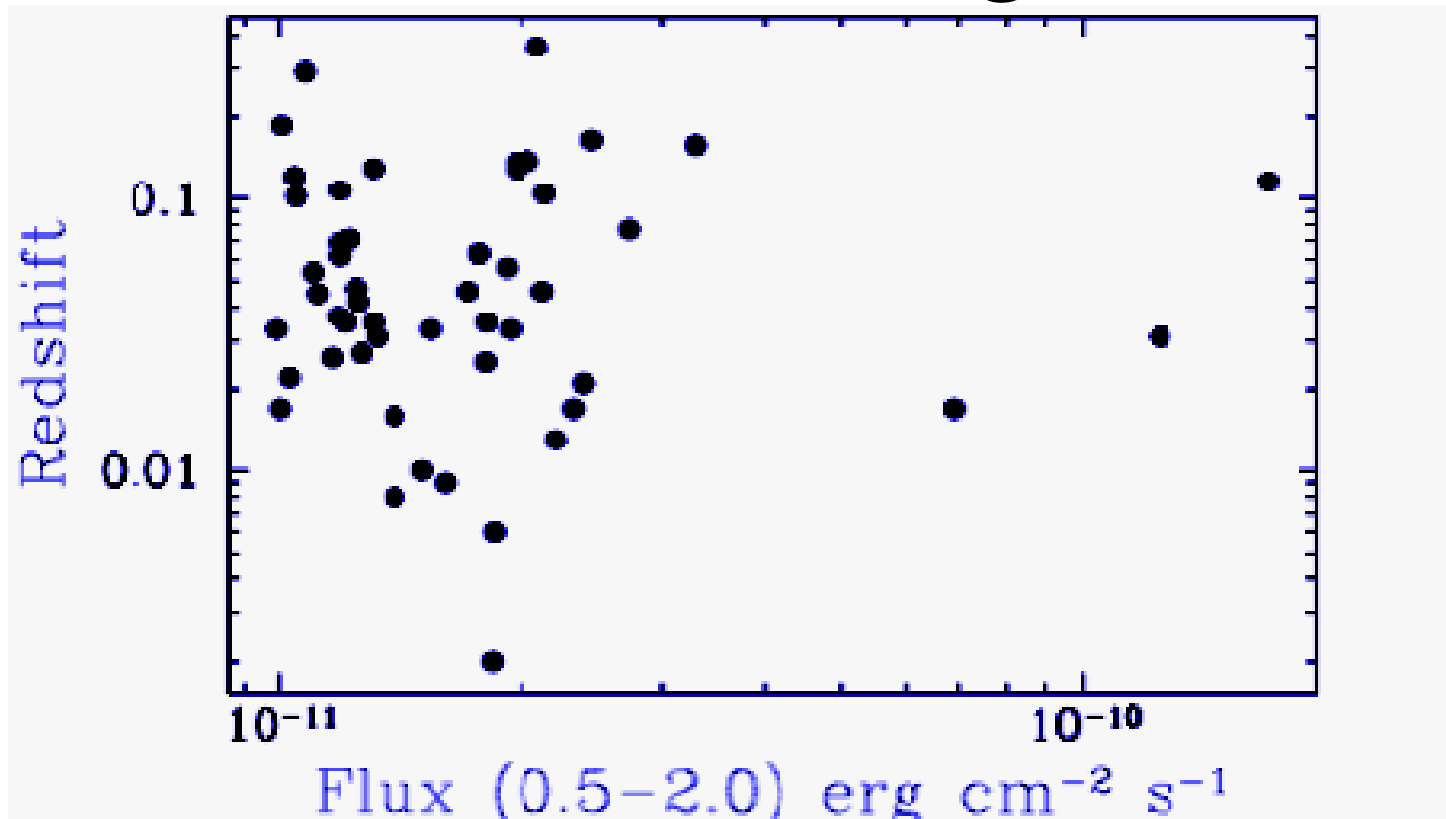


Cen & Fang 2006

Detecting the WHIM

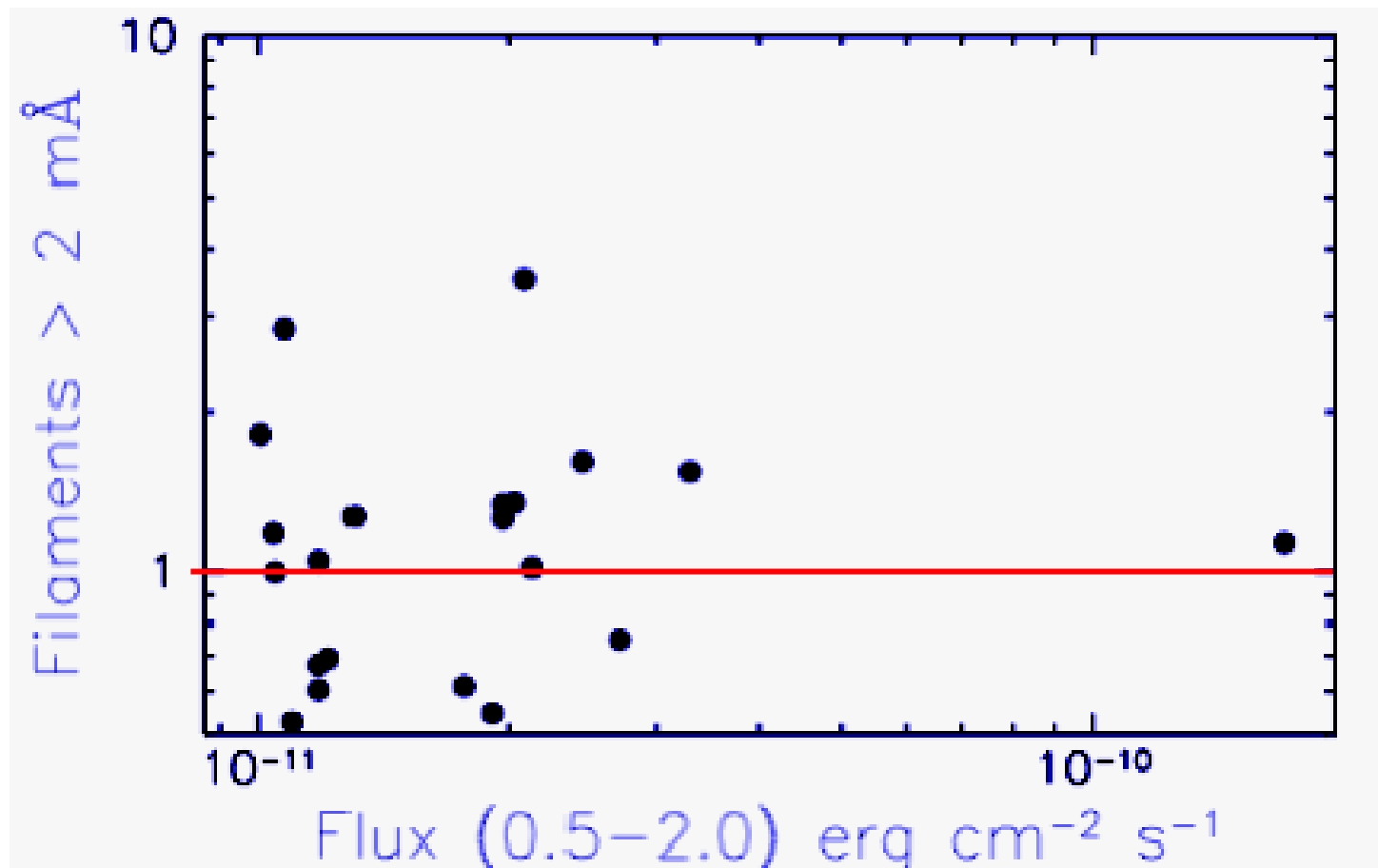
- To *find* the WHIM, we need:
 - **Bright** background AGN
 - **Dense** filaments
- Ideally, we want
 - Observations of both O VII and O VIII, as well as Ne IX and Ne X.
 - Resolved absorption lines to measure temperature/turbulence in the WHIM.

Where are the Bright AGN?



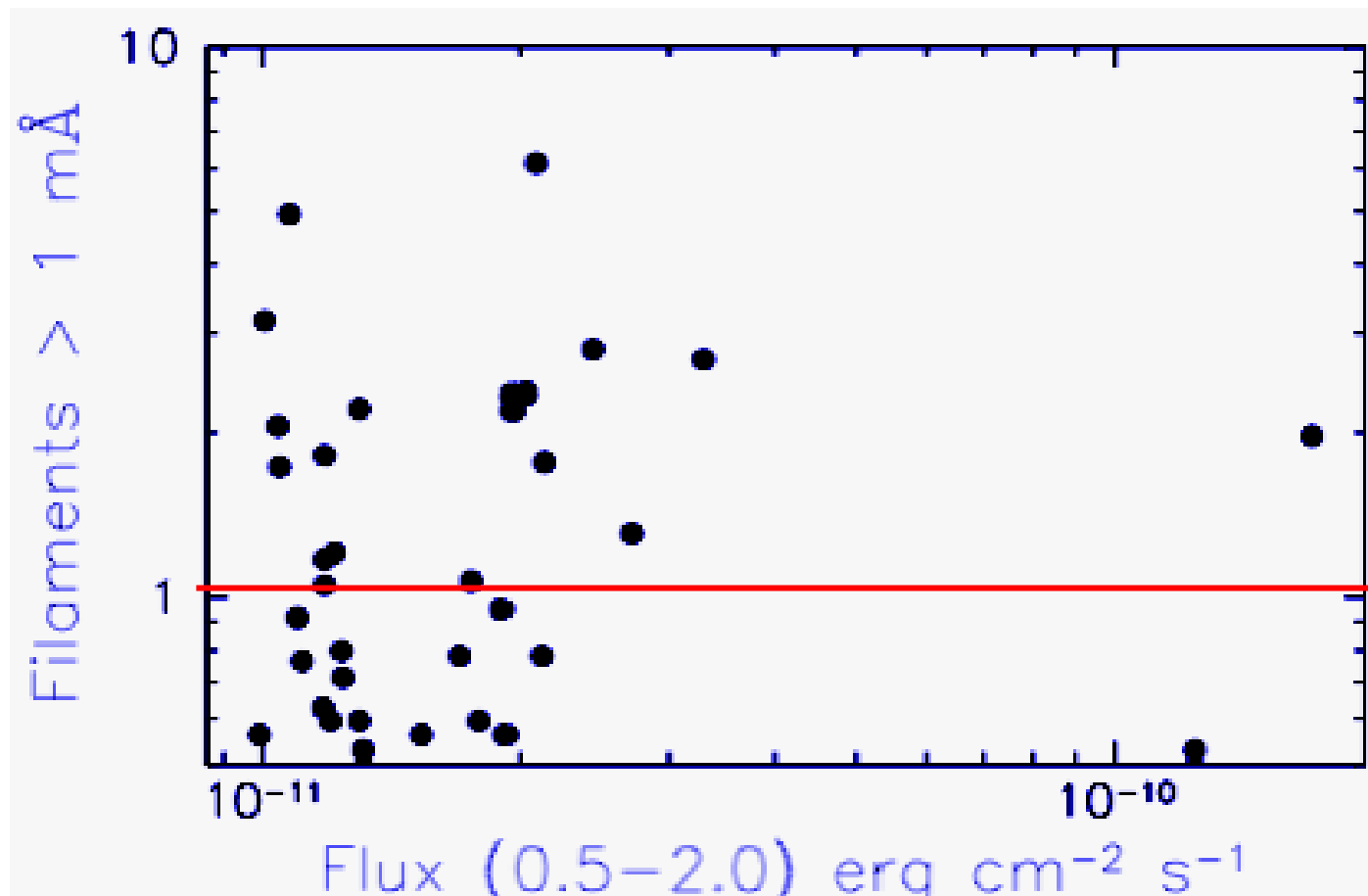
The Brightest 50 AGN from the ROSAT Survey
(generally nearby, with $F_X(0.5-2 \text{ keV}) > 10^{-11} \text{ erg/cm}^2/\text{s}$)

How Many Should Have Filaments?



Unsurprisingly, very dense filaments are rare.
(Using Cen & Fang 2006, ~12/50 AGN with EW > 2 mÅ)

How Many Should Have Filaments?



1mÅ filaments are much easier to find.
(~35 filaments in ~20/50 AGN with EW > 1 mÅ)

WHIM Simulations

- Bright, distant AGN
 - $\Gamma=2.0$, $N_H = 2 \times 10^{20} \text{ cm}^{-2}$
 - $z > 0.1$
 - $F_X(0.5\text{-}2 \text{ keV}) = 1.5 \times 10^{-11} \text{ erg/cm}^2/\text{s}$ (unabs)
- 3 O VII WHIM filaments
 - $z=0.01$, 0.5 mÅ ($N_{\text{OVII}} = 3.50 \times 10^{14} \text{ cm}^{-2}$)
 - $z=0.03$, 1.0 mÅ ($N_{\text{OVII}} = 6.67 \times 10^{14} \text{ cm}^{-2}$)
 - $z=0.10$, 2.0 mÅ ($N_{\text{OVII}} = 1.16 \times 10^{15} \text{ cm}^{-2}$)

*All 3 filaments are between 0.52-0.57 keV (21.8-23.8Å);
this was chosen as the easiest place to find filaments since
bright AGN are available.*



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure of Merit

For an unresolved line, $F \propto R\sqrt{EA}$

So at 0.54 keV (23 Å), we have:

	Resolution (FWHM)	Eff. Area (cm ²)	Figure of Merit
Baseline	270	8600	25000
Kelley	771	8600	71500
Flanagan	~1600	1000	50600
Lillie	3000	500	68100
Lillie #3	1000	10000	316200

Baseline Detection

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 100 ksec, $EW = 2 \text{ mÅ}$ *may* be detected ($2-3\sigma$)

Baseline Detection

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 300 ksec, $EW = 1 \text{ m}\text{\AA}$ is detected (5σ)

Baseline Detection

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 1 Msec, $EW = 1 \text{ m}\text{\AA}$ can be detected (7σ)

SEP: Kelley/GSFC

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 300 ksec, $EW = 0.5 \text{ m}\text{\AA}$ is marginal (4σ)

SEP: Flanagan/MIT

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 300 ksec, $EW = 1\text{m}\text{\AA}$ is detected (6σ)

SEP: Lillie/NGST & Colorado

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 300 ksec, $EW = 1\text{m}\text{\AA}$ is detected (5σ)

SEP: Lillie Option 3

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 300 ksec, $EW = 0.5 \text{ mÅ}$ is detected (8σ)

Conclusions

	100 ksec	300 ksec	1000 ksec
Base	$\sim 2 \text{ mÅ} (2\sigma)$	$1 \text{ mÅ} (5\sigma)$	$1 \text{ mÅ} (7\sigma)$
Kelley	$1 \text{ mÅ} (5\sigma)$	$\sim 0.5 \text{ mÅ} \square$ (4 σ)	$0.5 \text{ mÅ} (9\sigma)$
Flanagan	$\sim 1 \text{ mÅ} (4\sigma)$	$1 \text{ mÅ} (6\sigma)$	$\sim 0.5 \text{ mÅ} (4\sigma)$
Lillie	$\sim 2 \text{ mÅ} (2\sigma)$	$\sim 1 \text{ mÅ} (3\sigma)$	$\sim 0.5 \text{ mÅ} (4\sigma)$
Lillie #3	$1 \text{ mÅ} (7\sigma)$	$0.5 \text{ mÅ} (8\sigma)$	$0.5 \text{ mÅ} (11\sigma)$

This only considers detecting unresolved filaments. Higher resolution will allow better detection of any broadening.

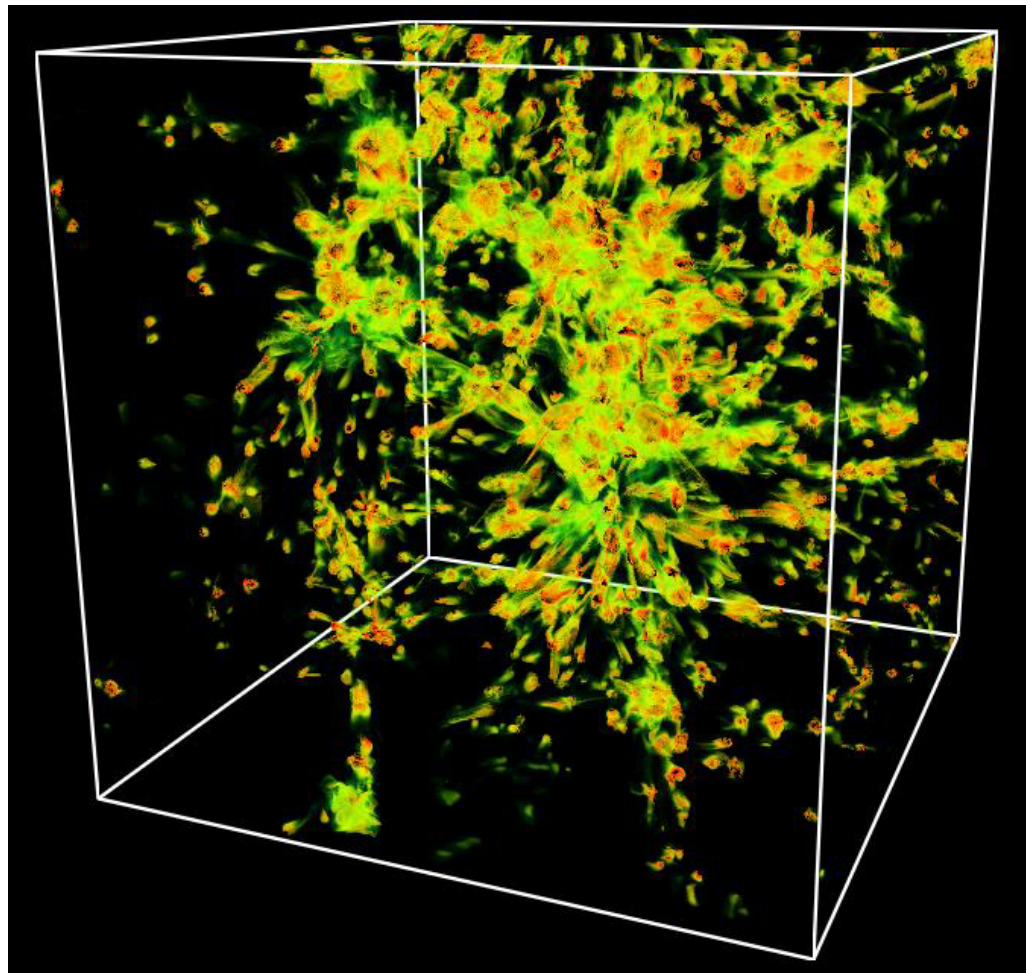
Conclusions

- With $\sim 50\,300$ ksec observations of bright AGN, the baseline Con-X will detect 30-50 Cen & Fang-type filaments.
- Once O VII is found, deeper observations can search for other ions.
- $R \sim 1500$ is needed to resolve filaments with velocity dispersion of 200 km/s , which is thought to be typical of the stronger absorption features.

O VII Filament Map

CDM+ Λ Model,
 $H_0=67$, $\Omega=0.30$,
 $\Omega_b=0.035$, $\Lambda=0.70$,
 $\sigma_8=0.90$

$L = 25\text{Mpc}/h$,
 $N_{\text{cell}}=768^3$



<http://www.astro.princeton.edu/~cen/PROJECTS/p2/p2.html>

SEP: Kelley/GSFC

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 100 ksec, $EW = 1 \text{ m}\text{\AA}$ is detected ($\sim 5\sigma$)

SEP: Kelley/GSFC

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 1 Msec, $EW = 0.5 \text{ m}\text{\AA}$ is detected ($\sim 9\sigma$)

SEP: Flanagan/MIT

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 100 ksec, $EW = 1 \text{ mÅ}$ is marginal ($\sim 4\sigma$).
Both 2nd & 3rd orders were used.

SEP: Flanagan/MIT

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 1 Msec, $EW = 0.5 \text{ mÅ}$ is marginal ($\sim 4\sigma$)

SEP: Lillie/NGST & Colorado

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 100 ksec, $EW = 2 \text{ mÅ}$ is marginal (2.5σ).

SEP: Lillie/NGST & Colorado

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 1 Msec, $EW = 0.5 \text{ m}\text{\AA}$ is marginal ($\sim 4\sigma$)

SEP: Lillie Option 3

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 100 ksec, $EW = 1 \text{ mÅ}$ is detected (7σ)

SEP: Lillie Option 3

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In 1 Msec, $EW = 0.5 \text{ m}\text{\AA}$ is detected (11σ)